WHAT IS CLAIMED IS:

Sub A2

1. An extended Maxwell pair comprising:

a pair of cylindrical gradient coils disposed coaxially around and along a z-axis extending in z-direction and symmetrically with respect to an origin, each being of radius a and of axial length d, said pair being mutually separated by a center-to-center distance z_0 which is greater than d; and

means for causing same currents to flow through said gradient coils in mutually opposite directions;

values of d and z_0 being selected such that said equal currents generate a magnetic field along said z-axis with a linear gradient near said origin in said z-direction.

2. The extended Maxwell pair of claim 1 further comprising a pair of cylindrical shield coils disposed coaxially around said gradient coils, each of said shield coils being of radius b which is greater than a, said means causing said equal currents to flow through said shield coils, said shield coils serving to cancel magnetic field outside said shield coils.

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3. The extended Maxwell pair of claim 1 wherein said magnetic field along said z-axis, when expanded in a polynomial form in z, does not include a cubic term.

4. The extended Maxwell pair of claim 2 wherein said magnetic field along said z-axis, when expanded in a polynomial form in z, does not include a cubic term.

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5. The extended Maxwell pair of claim 1 wherein each of said gradient coils comprises a helically rolled rectangular conductor sheet.

6. The extended Maxwell pair of claim 2 wherein each of said gradient coils comprises a helically rolled rectangular conductor sheet.

7. The extended Maxwell pair of claim 6 wherein each of said shield coils comprises a wire which is wound cylindrically at specified intervals, said intervals being determined such that said shield coils have effects of canceling magnetic field outside.

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8. The extended Maxwell pair of claim 1 wherein a and d are of a same order of magnitude.

9. The extended Maxwell pair of claim 2 wherein a, b, d and z_0 satisfy an equation given by $\int_0^{k_{max}} dk k^4 \{\sin(kd/2)\sin(kz_0/2)/(kd/2)\} S_0(k) K_0'(ka) I_0(k_\rho)=0$ where $S_0(k)=1-K_1(kb)I_1(ka)/K_1(ka)I_1(kb)$, I_1 and K_1 are modified Bessel functions, k_{max} is an appropriately selected upper limit of integration and ρ is an appropriately selected value less than a.

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10. The extended Maxwell pair of claim 9 wherein said gradient coils and said shield coils are structured such that said equal currents will have current distribution along said z-axis given by j and j respectively for said gradient coils and said shield coils, and an shielding equation given by

$$I^s(k) = -(a/b)(I_1(ka)/I_1(kb))I^p(k)$$

is satisfied where I_1 are modified Bessel functions of the first kind, Ip(k) and Is(k) are current density functions Ip(z) and Ip(z) respectively for said gradient coils and said shield coils Fourier-transformed into k-space, $I^p(z) = \int_{-\infty} dz' j^p(\varphi, z')$ and $I^s(z) = \int_{-\infty}^{z} dz' j^s(\varphi, z')$.

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11. A method of designing an extended Maxwell pair, said extended Maxwell pair comprising:

a pair of cylindrical gradient coils disposed coaxially around and along a z-axis extending in z-direction and symmetrically with respect to an origin, each being of radius a and of axial length d, said pair being mutually separated by a center-to-center distance z_0 which is greater than d; and

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a pair of cylindrical shield coils disposed coaxially around said primary coils, each of said shield coils being of radius b which is greater than a;

said method comprising the steps of:

specifying a gradient coil current distribution related to said gradient coils as equal currents are caused to flow through said gradient coils;

obtaining a shield coil current distribution related to said shield coils as said equal currents are also caused to flow through said shield coils such that magnetic field outside said shield coils is cancelled;

calculating resultant magnetic field near said origin due to said equal currents by Fourier-Bessel expansion method;

deriving from said calculated resultant magnetic field a linearity-establishing equation for obtaining a linear gradient around said origin; and

selecting a value of one of parameters selected from the group consisting of d and z_0 to solve said linearity-establishing equation for the other of said parameters.

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12. The method of claim 11 further comprising the step of designing said shield coils according to said derived shield coil current distribution.

13. The method of claim 11 wherein said linearity-establishing equation is given by

$$\int_0^{k_{max}} dk k^4 \{\sin(kd/2)\sin(kz_0/2)/(kd/2)\} S_0(k) K_0'(ka) I_0(k_p)=0$$

where $S_0(k)=1-K_1(kb)I_1(ka)/K_1(ka)I_1(kb)$, I_1 and K_1 are modified Bessel functions, k_{max} is an appropriately selected upper limit of integration and ρ is an appropriately selected value less than a.

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14. The method of claim 11 wherein said linearity-establishing equation is solved numerically.

15. The method of claim 12 wherein said linearity-establishing equation is solved numerically.

16. The method of claim 13 wherein said linearity-establishing equation is solved numerically.

17. The method of claim 11 further comprising the steps of:

calculating gradient coil current function $I^p(z) = \int_{\infty}^{z} dz' j^p(\varphi, z')$, where $j^p(\varphi, z')$ represents said specified gradient coil current distribution;

Fourier-transforming $I^p(s)$ into k-space to obtain $I^p(k)$;

obtaining a Fourier-transformed shield coil current function $I^s(k)$ in said k-space by a formula for canceling magnetic field outside said shield coils;

inverse Fourier-transforming $I^s(z)$ to obtain shield coil current function $I^s(z)$; and

determining positions of loops of a wire to be wound cylindrically to form said shield coils from said shield coil current function $I^s(z)$.

18. The method of claim 17 wherein said formula for canceling magnetic field out said shield coils is given by $I^s(k) = -(a/b)(I_1(ka)/I_1(kb))I^p(k)$.

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19. The method of claim 11 wherein a and d are of a same order of magnitude.

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